Insect Infestations, Incidence of Viral Plant Diseases, and Yield of Winter Wheat in Relation to Planting Date in the Northern Great Plains

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ABSTRACT   Planting date effects on arthropod infestation and viral plant disease are undocumented for winter wheat, *Triticum aestivum* L., in South Dakota and the northern Great Plains. Winter wheat was planted over three dates (early, middle, and late; generally from late August to late September) to determine the effect on abundance of insect pests, incidence of plant damage, incidence of viral plant disease, and grain yield. The study was conducted simultaneously at two sites in South Dakota over three consecutive cropping seasons for a total of six site yr. Cereal aphids (Homoptera: Aphididae) were abundant in three site yr. *Rhopalosiphum padi* (L.), bird cherry-oat aphid, was the most abundant cereal aphid at the Brookings site, whereas *Schizaphis graminum* (Rondani), greenbug, predominated at Highmore. Aphid-days were greater in early versus late plantings. Aphid abundance in middle plantings depended on aphid species and site, but it usually did not differ from that in early plantings. Incidence of Barley yellow dwarf virus (family *Luteoviridae*, genus *Luteovirus*, BYDV) declined with later planting and was correlated with autumnal abundance of cereal aphids. Incidence of BYDV ranged from 24 to 81% among 1999 plantings and was <8% in other years. Damage to seedling wheat by chewing insects varied for two site-years, with greater incidence in early and middle plantings. Wheat streak mosaic virus, spring infestations of cereal aphids, wheat stem maggot, and grasshoppers were insignificant. Yield at Brookings was negatively correlated with BYDV incidence but not cereal aphid abundance, whereas yield at Highmore was negatively correlated with aphid abundance but not BYDV incidence. Planting on 20 September or later reduced damage from chewing insects and reduced cereal aphid infestations and resulting BYDV incidence.

KEY WORDS   *Rhopalosiphum padi*, cereal aphids, Barley yellow dwarf virus, planting date

WINTER WHEAT, *Triticum aestivum* L., is a major grain crop grown in South Dakota and other areas of the northern Great Plains. It is established from late summer through autumn, undergoes winter dormancy, resumes growth in the spring, and matures by midsummer. In South Dakota, winter wheat is planted over a relatively wide range of dates generally from late August to mid-October, with the majority of acreage planted by the end of September (South Dakota Agricultural Statistics Service 2003). This range allows producers to include winter wheat within various cropping systems (e.g., wheat-fallow and multicrop systems), provides flexibility to accomplish other on-farm tasks, and enables growers to exploit timely rains and ample soil moisture for wheat establishment.

Winter wheat is subject to infestation by several arthropod pests and to infection by two major arthropod-vectored viral diseases. In South Dakota, the arthropod pest complex can be divided into two categories based on the stage of winter wheat that is attacked. First, winter wheat in the seedling-to-tillering stages may be infested by a complex of cereal aphids (Homoptera: Aphididae), by *Aceria tosichella* Kiefer, wheat curl mite (Acari: Eriophyidae), and by a complex of chewing insects. The cereal aphid complex in South Dakota winter wheat includes *Rhopalosiphum padi* (L.), bird cherry-oat aphid; *Rhopalosiphum maidis* (Fitch), corn leaf aphid; *Rhopalosiphum rufiabdominalis* (Sasaki), rice root aphid; *Schizaphis graminum* (Rondani), greenbug; and *Sitobion avenae* (F.), English grain aphid (Kieckhefer and Gustin 1967). These cereal aphids cause yield loss in winter wheat (Pike and Schaffner 1985, Kieckhefer and Gellner 1992, Kindler et al. 2002). Their population levels can fluctuate considerably throughout the growing season and are often expressed cumulatively in units of aphid-days (Chapin et al. 2001, Kindler et al. 2002, Hesler and Berg 2003). Cereal aphids are also impor-

tant because they vector Barley yellow dwarf virus (family *Luteoviridae*, genus *Luteovirus*, BYDV; Hewings and Eastman 1995), which causes disease and yield loss in winter wheat (Fitzgerald and Stoner 1967, Riedell et al. 1999). Direct damage to wheat by fall infestations of *A. tosichella* is considered insignificant, but *A. tosichella* vectors Wheat streak mosaic virus (family *Potyviridae*, genus *Tritimovirus*, WSMV; Slykhuis 1955). This causes disease and yield loss in winter wheat (Atkinson and Grant 1967), and incidence of WSMV in winter wheat is minimized by practices that limit *A. tosichella* infestations (Slykhuis et al. 1957, Harvey et al. 1979). The complex of chewing insects is comprised of several pests that occasionally cause yield loss in winter wheat (Morrill 1995), including grasshoppers (Orthoptera: Acrididae), crickets (Orthoptera: Gryllidae), cutworms (Lepidoptera: Noctuidae), wireworms (Coleoptera: Elateridae), false wireworms (Coleoptera: Tenebrionidae), and flea beetles (Coleoptera: Chrysomelidae). The army cutworm, *Euxoa auxiliaris* (Grote), and pale western cutworm, *Agrotis orthogonia* Morrison (Lepidoptera: Noctuidae), occasionally attack winter wheat in South Dakota, but significant populations are restricted to south central portions of the state. The Hessian fly, *Mayetiola destructor* (Say), is a widespread pest of wheat in North America, but it has had little economic impact in South Dakota (Walgenbach et al. 1978)

From the time when the last leaf has emerged through early stages of seed head maturation, winter wheat is subject to further infestation by insect pests. Cereal aphids may reinfest winter wheat in the spring and occasionally reach economically significant levels on stems and developing heads (Kieckhefer and Kantack 1988). Larvae of the wheat stem maggot, *Meromyza americana* Fitch (Diptera: Chloropidae), feed inside the culm after heads form, and they sever conductive tissue and prevent kernel formation, leading to direct yield loss (Gilbertson 1925, Kieckhefer and Morrill 1970). Finally, grasshoppers can feed directly upon developing heads or upon peduncles to the extent that the head is severed or lodges (Morrill 1995).

Arthropod pests cause economic damage when sufficient numbers of them coincide temporally and spatially with a host crop (Teetes 1981, All 1999). Varying the date of planting may disrupt phenological synchrony between pests and crop (All 1999). Most crops have a range in time over which they may be planted and still yield well. Planting date modification is a potential cultural control because wheat may be planted over a range of dates and produce a crop of acceptable yield and quality (Burnett and Plumb 1998, Peairs 1998). Often, however, planting date modification is targeted against only one or a few arthropod pests for a particular crop, but could exacerbate problems with other pests (Teetes 1981, All 1999). The effect of planting date on the nature and severity of arthropod infestation and viral plant disease is undocumented for winter wheat in South Dakota and the northern Great Plains. Therefore, we conducted a study in winter wheat in South Dakota to determine whether arthropod infestation, incidence of viral plant disease, and yield vary in relation to planting date.

Materials and Methods

Study Sites. Our study was conducted at two sites during the 1999–2000, 2000–2001, and 2001–2002 winter wheat cropping seasons in South Dakota. One set of study plots was located at the Eastern South Dakota Soil and Water Research Farm in central Brookings County, and a second set was located at the Central Crops Research Station near Highmore in Hyde County. Each set of plots annually had three treatments representing relatively early, intermediate, and relatively late (designated early, middle, and late) plantings of winter wheat. Exact dates of planting and other agronomic details about the plots are given in Table 1. At each site, treatments were arranged in a randomized complete block with four to six replications. At Brookings, winter wheat in 1999 was planted into chisel-plowed plots, whereas in 2000 and 2001, winter wheat was planted into nontilled canola, *Brassica napus* L., stubble. At Highmore, winter wheat was planted into chisel-plowed plots. Plots received no applications of postemergent pesticides, but they were sprayed sometimes ≈2 wk before planting (Brookings, August 2000: bromoxynil [0.4 kg [AI] ha^{-1}], MCPA ester [0.4 kg [AI] ha^{-1}] and glyphosate [1.7 kg [AI] ha^{-1}]; Brookings and Highmore, August 2001: glyphosate [1.7 kg [AI] ha^{-1}]) to control emerged weeds.

Autumnal Insect Samples. *Cereal Aphids.* Seedling wheat was sampled for aphid infestations and chewing insect damage at 1- to 2-wk intervals from mid-September to as late as early December when weather permitted (1999, Brookings). On each sampling date, we examined 25 tillers (from five groups of five plants) per plot. For each 25-tiller sample, we counted cereal aphids per tiller and were careful to look for aphids at or slightly below ground level to detect cryptic populations of *R. rufiabdominalis* and *R. padi* (Kieckhefer and Gustin 1967, Hesler and Berg 2003). We identified aphids to species in the field with unaided eyes or a 10× hand lens and occasionally in our laboratory by using a stereomicroscope with keys by Stoetzel (1987) or Blackman and Eastop (1984). We summed the number of cereal aphids per plot across sampling dates each year. Graphically, this sum formed a polygon, and its area was a cumulative measure of cereal aphid density expressed in aphid-days (Ruppel 1983, Chapin et al. 2001, Hesler and Berg 2003). We calculated the area under the polygon (AUP) by the following equation: $\text{AUP} = \Sigma \ (t_{i+1} - t_i) \ (y_i + y_{i+1})/2$, where y_1 and y_{i+1} are numbers of cereal aphids per 25 tillers (per plot), respectively, on consecutive Julian sampling dates, t_i and t_{i+1} (Ruppel 1983). We assumed all aphid counts were zero on the seventh day after planting and used that as the start date for AUP calculations. AUP values were compared between tillage treatments by a one-way analysis of variance (ANOVA) by using planting date as the independent variable (PROC ANOVA, SAS Institute 1999). The AUP values for *R. padi* and *S. avenae* at Highmore in 1999 were each

Table 1. Agronomic profiles of winter wheat experimental plots in South Dakota

			Seeding		Planting date		
Yr	Variety[a]	Site[b]	Rate (kg ha⁻)	Plot size (m²)	Early	Middle	Late
1999	Roughrider	Brookings	135.5	9.7 by 34.0	31 Aug.	10 Sept.	20 Sept.
		Highmore	137.8	9.7 by 35.0	9 Sept.	18 Sept.	27 Sept.
2000	Crimson	Brookings	116.5	9.1 by 18.2	30 Aug.	11 Sept.	27 Sept.
		Highmore	137.8	9.7 by 18.2	31 Aug.	11 Sept.	25 Sept.
2001	Crimson	Brookings	123.2	9.1 by 18.2	31 Aug.	10 Sept.	21 Sept.
		Highmore	137.8	9.7 by 18.2	31 Aug.	10 Sept.	25 Sept.

Year	Variety[a]	Site[b]	Fertilizer (% N-P-K, kg ha⁻¹)[c]
1999	Roughrider	Brookings	BP: 14–15–11, 112. TD: 46–0–0, 336
		Highmore	BC: 46–0–0, 112
2000	Crimson	Brookings	BP: 14–15–11, 112. TD: 46–0–0, 379
		Highmore	BC: 46–0–0, 112
2001	Crimson	Brookings	BP: 14–15–11, 112. TD: 46–0–0, 379; 0–0–27, 59; 0–15–11, 110
		Highmore	BP: 14–15–11, 112. BC: 46–0–0, 112

[a] 'Roughrider' (Erickson et al. 1977) seed treated with fungicides (mixture of 17% [AI] carboxin and 17% [AI] thiram, 0.3 ml [product]/kg); 'Crimson' (Haley et al. 1998) seed treated with fungicides (mixture of 10% [AI] carboxin and 10% [AI] thiram, 0.4 ml [product]/kg).

[b] At Brookings, seed sown with single-disc drill ≈2.5 cm in depth in rows 19 cm apart. At Highmore, seed sowed with furrow drill ≈2.5 cm in depth in rows 30.5 cm apart.

[c] BC, broadcast before planting; BP, banded at planting; and TD, spring top-dress application.

square-root transformed to standardize variances before analyses (Zar 1996). A protected least significant difference (LSD) test ($P < 0.05$; Fisher 1935) was used to separate means for individual site-year combinations.

Chewing Herbivores. For each 25 tillers used to sample for aphids, we also counted the number of plants damaged by chewing herbivores (i.e., insects such as grasshoppers, wireworms and cutworms, or small mammals). We classified tillers as damaged by chewing herbivores if the tips or margins of leaves had uneven edges, irregular-shaped holes or skeletonization, or if tillers were severed near the ground. The incidence of damage from chewing herbivores (as a group) was expressed as a percentage per plot. Data from site-years with mean damage incidence >10% were transformed (arcsine square root, Zar 1996) and subjected to a one-way ANOVA by using planting date as the independent variable (PROC ANOVA, SAS Institute 1999). A protected LSD ($P < 0.05$) was calculated to separate means for individual site-years. Data from site years in which wheat seedlings had <10% damage were not subjected to analysis.

Late Spring Insect Samples. Twenty-five tillers per plot were sampled for cereal aphids in late spring each year during the time of seed head emergence. The mean numbers of aphids per 25-tiller sample were subjected to a one-way ANOVA (planting date as the independent variable), but site-years with low aphid numbers (mean <3 aphids per 25 tillers) were not analyzed.

Wheat was sampled for infestation by *M. americana* larvae during the milk-to-early dough stages of grain development by using methods similar to those of Kieckhefer and Morrill (1970). First, all wheat heads were counted within five (year 2000, Brookings) or 10 quadrats (0.09-m² subsamples) per plot (summers 2001 and 2002, Brookings and Highmore). The upper node of individual tillers with pale, discolored heads

was gently pulled from the tiller and examined. Those nodes with pale green, *M. americana* larvae, frass, or feeding damage at the base were counted as *M. americana*-infested. Both the number of *M. americana*-infested tillers and total number of tillers were summed across all quadrats within each plot, and percentage infestation per plot was expressed as a ratio of total number of *M. americana*-infested tillers to total number of grain heads.

We sampled for grasshoppers and crickets within treatment plots at one to two times each year after wheat heads had emerged. Sampling consisted of an individual walking along a 20-m transect centered within each plot and counting all grasshoppers and crickets seen within an ≈1-m-wide swath of transect.

Viral Diseases. We sampled for viral diseases in wheat during late spring by walking through plots in a W-shaped pattern and classifying ≈200 (year 2000) or 300 (years 2001 and 2002) randomly selected plants per plot as either having or not having visual symptoms of BYDV (flag leaves with yellow or purple tips but base remaining green) or WSMV (mottling or long yellow streaks concentrated at leaf tips). Visual symptoms and enzyme-linked immunosorbent assay results were well correlated in previous field surveys to determine incidence of BYDV and WSMV in wheat (unpublished data). Thus, only visual sampling was used. The incidence of each viral disease was expressed as a percentage of plants infected per plot. Data from site-years with disease incidence >10% were transformed (arcsine square root, Zar 1996) and subjected to a one-way ANOVA (PROC ANOVA, SAS Institute 1999) by using planting date as the independent variable. A protected LSD ($P < 0.05$) was calculated to separate means within individual site-years. Data from site years with viral infection rates <10% were not subjected to analysis. We tested for correlation (PROC CORR, SAS Institute 1999) between BYDV incidence and cereal aphid abundance in autumn

Table 2.   Autumnal aphid-day accumulations per 25 tillers (± SEM) among winter wheat plantings in South Dakota

Yr	Site	Taxon	Early planting	Middle planting	Late planting
1999	Brookings	*R. padi*	6,402.3 ± 1,234.7aA	3,682.6 ± 736.7bA	2,340.1 ± 124.6bA
		R. maidis	1,547.6 ± 369.7aB	1,863.3 ± 263.5aB	494.1 ± 156.2bB
		R. rufiabdominalis	17.8 ± 7.3aC	37.5 ± 23.9aD	6.3 ± 6.3aD
		Schizaphis graminum	125.4 ± 73.1aC	282.6 ± 50.7aC	174.6 ± 48.0aC
		Sitobion avenae	17.0 ± 5.7aC	32.9 ± 21.3aD	31.5 ± 20.0aD
		Total cereal aphids	8,110.0 ± 1,455.7a	5,898.9 ± 665.7ab	3,046.6 ± 226.9b
1999	Highmore	*R. padi*	333.6 ± 54.7aB	103.7 ± 16.5bB	10.9 ± 4.5cB
		R. maidis	194.1 ± 27.0aBC	108.4 ± 45.2bB	10.9 ± 5.2bB
		R. rufiabdominalis	0.0 ± 0.0aD	0.0 ± 0.0aC	0.0 ± 0.0aB
		S. graminum	1,002.4 ± 223.7aA	1,403.8 ± 275.9aA	43.8 ± 13.2bA
		S. avenae	124.5 ± 42.8aC	100.3 ± 61.6aBC	15.8 ± 10.2bB
		Total cereal aphids	1,654.6 ± 214.3a	1,716.1 ± 280.2a	81.5 ± 16.1b
2000	Brookings	Total cereal aphids	—[b]	—	—
2000	Highmore	Total cereal aphids	—	—	—
2001	Brookings	*R. padi*	7,022.9 ± 634.5aA	5,802.5 ± 889.3aA	2,090.4 ± 597.2bA
		R. maidis	1,303.4 ± 148.3aB	733.9 ± 58.2bB	54.8 ± 29.2cB
		R. rufiabdominalis	5.3 ± 5.3aC	0.0 ± 0.0aC	0.0 ± 0.0aB
		S. graminum	16.6 ± 16.6aC	0.0 ± 0.0aB	40.0 ± 23.2aC
		S. avenae	8.5 ± 5.2aC	0.0 ± 0.0aC	0.0 ± 0.0aB
		Total cereal aphids	8,356.6 ± 674.6a	6,536.4 ± 922.8a	2,185.1 ± 568.1b
2001	Highmore	*R. padi*	2.6 ± 2.6	2.6 ± 2.6	2.5 ± 2.5
		R. maidis	5.3 ± 5.3	19.0 ± 11.1	2.5 ± 2.5
		R. rufiabdominalis	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
		S. graminum	0.0 ± 0.0	38.5 ± 23.3	0.0 ± 0.0
		S. avenae	0.0 ± 0.0	2.6 ± 2.6	0.0 ± 0.0
		All cereal aphids	7.9 ± 7.9	62.8 ± 22.1	5.0 ± 5.0

For each site-year and aphid taxon, means ± SEM within a row followed by the same lowercase letter do not differ significantly ($P < 0.05$; Fisher's protected LSD). For each site-year and planting, means within a column followed by the same uppercase letter do not differ significantly ($P < 0.05$; Fisher's protected LSD). Aphid-days as defined by Ruppel (1983). Data for *R. padi* and *S. avenae* at Highmore, 1999–2000, analyzed as square root ($x + 0.5$) to standardize variances. Early, middle, and late plantings for Brookings and Highmore, respectively: 31 Aug., 10 Sept., 20 Sept. and 9 Sept., 18 Sept., 27 Sept., 1999; 30 Aug., 11 Sept., 27 Sept. and 31 Aug., 11 Sept. 11, 25 Sept., 2000; and 31 Aug., 10 Sept., 21 Sept. and 31 Aug., 10 Sept., 22 Sept., 2001.

[a] Sampling periods: Brookings, 10 Sept.–7 Dec., 1999 and 13 Sept.–14 Nov., 2001; Highmore, 27 Sept.–22 Nov., 1999 and 20 Sept.–25 Oct., 2001.

[b] Aphid-days not calculated because less than five aphids sampled across all plots.

(aphid-days per 25 tillers) and in spring (number per 25 tillers).

Yield Data. A Massey–Ferguson 8XP small-plot combine was used to harvest one to two, 1.5-m-wide combine strips within each plot; exact measurements of strips were made immediately after each combine pass. Yield per plot was converted and expressed on a per-hectare basis for comparison. Moisture was measured for each combine strip sample and subtracted to derive a dry mass of harvested grain (megagrams per hectare, Mg ha^{-1}). We tested for correlation (PROC CORR, SAS Institute 1999) between cereal aphid abundance and yield and between BYDV incidence and yield.

Results

Observations on Wheat Seedling Emergence, Weeds, and Shoot Diseases. Wheat plants emerged roughly 7 d after planting, and seedlings filled rows in autumn 1999 and 2001. In contrast, lack of soil moisture inhibited wheat emergence of all plantings in 2000 until ≈5 October at Brookings following light rain. At Highmore in 2000, wheat emergence was spotty in the early and middle plantings, with ≈50% of row length filled with wheat seedlings until after 5 October, when rows within each planting filled as remaining wheat seeds germinated and seedlings emerged after light rain.

Weed pressure was light for all site-years. Low densities of tansy mustard, field pennycress, and dandelion were present in field plots. Grassy weeds were present at very low densities.

Plant diseases that show symptoms on wheat shoots were not problematic in our study. Low incidence of the fungal disease tan spot was observed in early summer 2001 and 2002 on wheat plants in our plots. We did not notice infestations of leaf rust and scab in our plots.

Autumnal Insect Samples. *Cereal Aphids.* We collected five species of cereal aphids: *R. padi*, *R. maidis*, *R. rufiabdominalis*, *S. graminum*, and *S. avenae* (Table 2). All five species were found at Brookings, whereas all species except *R. rufiabdominalis* were found at Highmore. Cereal aphids were abundant in wheat at Brookings in autumn 1999 and 2001 and moderately abundant in Highmore in autumn 1999, but their levels were very low in autumn 2000 at Brookings and Highmore and in autumn 2001 at Highmore. Thus, analysis of aphid-day data was restricted to Brookings in 1999 and 2001 and Highmore in 1999.

Abundance of individual cereal aphid species varied within plantings. *R. padi* was the most abundant cereal aphid in each planting at Brookings in autumn 1999 (early, $F = 51.3$; middle, $F = 48.6$; late, $F = 65.2$; df = 4, 15; $P < 0.01$) and autumn 2001 (early, $F = 259.9$; middle, $F = 169.5$; late, $F = 29.2$; df = 4, 15; $P < 0.01$). *R. maidis* was second-most abundant across all plantings at Brookings in 1999 and 2001. Other cereal aphids

Table 3. Incidence of seedlings damaged (mean percentage ± SEM) by chewing insects among winter wheat plantings in South Dakota

Growing season	Site	Planting		
		Early	Middle	Late
1999–2000	Brookings	17.8 ± 2.5a	15.9 ± 1.8a	7.8 ± 1.8b
	Highmore	2.5 ± 0.8	1.0 ± 0.5	0.7 ± 0.3
2000–2001	Brookings	—[a]		
	Highmore	62.6 ± 4.6a	70.0 ± 7.7a	22.0 ± 3.5b
2001–2002	Brookings	3.8 ± 1.0	3.4 ± 2.0	4.1 ± 0.4
	Highmore	2.6 ± 1.5	3.7 ± 1.7	4.0 ± 1.6

Means ± SEM within a row followed by the same letter do not differ statistically ($P < 0.05$; Fisher's protected LSD). Percentages were analyzed as arcsine square root, but actual means are presented.

[a] Damage not recorded because emergence of wheat was delayed until populations of chewing insects had greatly diminished.

were relatively low in abundance. At Highmore in 1999, *S. graminum* was the most abundant cereal aphid across plantings (early, $F = 32.8$; middle, $F = 29.5$; late, $F = 3.7$; df = 4, 25; $P < 0.05$). *R. padi, R. maidis,* and *S. avenae* were intermediate in abundance in the early and middle plantings. In the late planting, aphid-day accumulations for *R. padi, R. maidis, R. rufiabdominalis,* and *S. avenae* were low or zero and did not differ from one another.

Planting date generally affected aphid abundance. At Brookings, cereal aphids were more abundant in the early than in the late planting in 1999 ($F = 9.11$; df = 2, 6; $P < 0.05$). Their abundance was intermediate in the middle planting. In 2001, more cereal aphids were found in early and middle plantings than in the late planting ($F = 28.48$; df = 2, 6; $P < 0.01$). More *R. padi* were found in the early planting than in middle and late plantings in 1999 ($F = 7.97$; df = 2, 6; $P < 0.05$), whereas in 2001 early and middle plantings had more *R. padi* than the late planting ($F = 21.31$; df = 2,6; $P < 0.01$). More *R. maidis* were found in early and middle plantings than in the late planting in 1999 ($F = 7.79$; df = 2, 6; $P < 0.05$), but *R. maidis* aphid-days were greatest in the early planting, intermediate in the middle planting, and least in the late planting in 2001 ($F = 50.18$; df = 2,6; $P < 0.01$). Aphid-days for *R. rufiabdominalis, S. graminum,* and *S. avenae* were low and did not differ by planting date.

At Highmore, cereal aphids were most abundant in the early and middle plantings in 1999 ($F = 23.40$; df = 2, 10; $P < 0.01$). Early and middle plantings had more *S. graminum* than the late planting in 1999 ($F = 10.83$; df = 2, 10; $P < 0.01$). *R. padi* was most abundant in the early planting, intermediate in the middle planting, and least abundant in the late planting ($F = 23.40$; df = 2, 10; $P < 0.01$). More *R. maidis* were found in the early planting, but abundance did not differ between middle and late plantings ($F = 14.46$; df = 2, 10; $P < 0.01$). Populations of *S. avenae* were light in 1999, but greater in early and middle plantings than in the late planting ($F = 3.01$; df = 2, 10; $P < 0.05$).

Chewing Herbivores. Substantial numbers of wheat seedlings were damaged in autumn by chewing herbivores in two of six site-years (Table 3). In both instances, the incidence of damage varied ($P < 0.01$)

by planting (Brookings, 1999: $F = 17.5$; df = 2, 6; Highmore, 2000: $F = 43.7$; df = 2, 6), with incidence in early and middle plantings greater than in the late planting. More than half of the plants sampled in the early and middle plots at Highmore in autumn 2000 had incurred damage from chewing herbivores, whereas <18% of wheat plants were damaged in other plots across site-years. Damage was usually limited to leaf tips, small lengths along the margins of leaves, small irregular-shaped holes, or small patches of skeletonized leaves. This damage was characteristic of that from insects such as grasshoppers, crickets, wireworms, and flea beetles (Morrill 1995). Indeed, we occasionally observed grasshoppers, crickets and flea beetles, but not wireworms, feeding upon wheat in our plots. In 2000, short lengths of seed furrow were occasionally dug to check seeds for germination and insect damage, but insect damage typical of wireworms and false wireworms was absent. We did not measure the degree of defoliation, but, as damage was typically limited to small areas of leaf tissue, we estimate that individual damaged plants generally suffered <20% defoliation across site-years.

Late Spring Insect Samples. *Cereal Aphids.* Cereal aphids were relatively abundant, but they did not vary by planting date ($P > 0.05$) at Brookings in spring 2001 (mean ± SEM, 21.8 ± 5.9 aphids per 25 tillers; $F = 0.80$; df = 2, 6) or at Highmore in spring 2000 (mean ± SEM, 27.3 ± 4.9 aphids per 25 tillers; $F = 1.55$; df = 2, 10) and spring 2001 (mean ± SEM, 11.6 ± 4.9 aphids per 25 tillers; $F = 0.77$; df = 2, 6). Mean abundance was <3 aphids per 25 tillers at Brookings in spring 2000 and 2002 and at Highmore in spring 2002, and these data were not analyzed statistically. *R. padi* made up >90% of all cereal aphids sampled in the spring, except at Highmore in spring 2000, where samples consisted of 42% *R. padi* and 58% *S. avenae.*

M. americana Larvae, Grasshoppers, and Crickets. Incidence of larval infestation of winter wheat by *M. americana* averaged <0.6% per site-year. Counts of grasshoppers and crickets during the early stages of seed head maturation averaged <1.5 per 20-m transect for each site-year. These infestation levels could not have meaningfully impacted overall plant growth and yield.

Viral Plant Diseases. The incidence of viral plant diseases is given in Table 4. Incidence of BYDV was relatively high in 1999–2000 and varied by planting at Brookings ($F = 28.66$; df = 2, 6; $P < 0.01$) and Highmore ($F = 7.62$; df = 2, 10; $P < 0.01$). At Brookings, incidence was greatest in the early planting, intermediate in the middle planting, and lowest in the late planting, whereas at Highmore incidence in the early planting was higher than in the late planting. In 2000–2001 and 2001–2002, incidence of BYDV was <8%. Incidence of BYDV correlated ($P < 0.05$) with aphid-day accumulations for total cereal aphids ($r = 0.53$), *R. padi* ($r = 0.43$), and *R. maidis* ($r = 0.70$) at Brookings, and with total aphid-days ($r = 0.77$) and *S. graminum* aphid-days ($r = 0.67$) at Highmore. Spring abundance of cereal aphids had a weak inverse relationship to barely yellow dwarf incidence at Brookings ($r =$

Table 4. Incidence of Barley yellow dwarf virus (mean percentage of plants infected ± SEM) among winter wheat plantings in South Dakota

Growing season	Site	Planting		
		Early	Middle	Late
1999–2000	Brookings	87.1 ± 2.6a	66.4 ± 5.7b	40.1 ± 6.7c
	Highmore	41.9 ± 3.8a	34.4 ± 4.2ab	24.4 ± 2.1b
2000–2001	Brookings	1.3 ± 0.3	1.4 ± 0.4	1.3 ± 0.3
	Highmore	3.2 ± 0.9	0.6 ± 0.3	1.3 ± 0.6
2001–2002	Brookings	8.1 ± 0.4	7.3 ± 0.7	7.0 ± 1.3
	Highmore	4.6 ± 0.7	3.7 ± 0.9	5.7 ± 1.5

Means ± SEM within a row followed by the same letter do not differ statistically ($P < 0.05$; Fisher's protected LSD). Percentages were analyzed as arcsine square root, but actual means are presented.

−0.34) and a nonsignificant relationship at Highmore. Incidence of WSMV never exceeded 7% for any site-year and did not differ among plantings.

Yield. Yield varied ($P < 0.05$) with planting date for two of six site-years (Table 5). At Brookings, middle and late plantings had greater yields than the early planting for 1999–2000, and the early and middle plantings out-yielded the late planting for 2001–2002. Over the 3 yr of the study, yield at Brookings was negatively correlated ($P < 0.05$) with BYDV incidence ($r = -0.75$) but not cereal aphid abundance, whereas yield at Highmore was negatively correlated with cereal aphid abundance ($r = -0.37$, $P < 0.05$) but not BYDV incidence.

Discussion

For the three site-years with substantial aphid abundance, aphid-days were greater in early than late plantings. Aphid abundance in the middle planting depended on aphid species and site and usually did not differ statistically from that in early planting. Incidence of BYDV declined with later planting. Thus, our results in South Dakota agree with studies in other locations that relatively late plantings of winter cereals reduce autumnal abundance of aphids and incidence of BYDV compared with early planting (Snidaro and Delogu 1990, Hammon et al. 1996, Chapin et al. 2001, Kelley 2001, Kennedy and Connery 2001, Royer et al. 2005).

Table 5. Yield among winter wheat plantings in South Dakota over three growing seasons

Location	Planting	Mg/ha (± SEM)		
		1999–2000	2000–2001	2001–2002
Brookings	Early	2.69 ± 0.07a	3.49 ± 0.05	3.50 ± 0.04a
	Middle	3.23 ± 0.15b	3.53 ± 0.11	3.52 ± 0.06a
	Late	3.33 ± 0.12b	3.47 ± 0.07	3.24 ± 0.03b
	F (df)	9.15 (2, 6)	0.14 (2, 6)	21.74 (2, 6)
Highmore	Early	1.49 ± 0.28	1.51 ± 0.24	1.97 ± 0.37
	Middle	1.57 ± 0.29	2.06 ± 0.12	1.90 ± 0.51
	Late	1.85 ± 0.23	2.05 ± 0.08	1.93 ± 0.37
	F (df)	1.20 (2, 10)	3.82 (2, 6)	0.02 (2, 4)

Means within a location and season followed by different letters differ significantly ($P < 0.05$; Fisher's protected LSD).

Incidence of BYDV was correlated with autumnal abundance of cereal aphids. This result agrees with that of Chapin et al. (2001), who found that BYDV incidence was correlated with *R. padi* aphid-day accumulation. Although cereal aphid abundance was correlated with BYDV incidence at Brookings over the 3 yr of our study, incidence in 1999–2000 was ≈10 times higher than in 2001–2002 despite similar infestation levels and species composition of cereal aphids each year. Several factors influence BYDV incidence of autumn-sown cereal crops, including 1) cereal aphid infestation levels, 2) aphid infectivity, 3) crop growth stage, 4) virus spread within crops, and 5) resistance or differential symptom expression among wheat varieties to BYDV (Plumb et al. 1986, Burnett and Plumb 1998). These factors are considered below.

Cereal aphid infestations of wheat occurred in fall and spring of both the 1999–2000 and 2001–2002 cropping seasons. Fall infestations were similar each year in the number of aphid-days accumulated. Spring infestations of cereal aphids in winter wheat plots each season were light and had a weak inverse correlation to BYDV incidence at Brookings. The similar fall and spring infestation levels of cereal aphids also would indicate a similar rate of virus spread between the 1999–2000 and 2001–2002 cropping seasons. Furthermore, planting dates and crop development were similar between seasons, and therefore crop growth stage was an unlikely factor to account for differences in BYDV incidence between 1999–2000 and 2001–2002.

Our winter wheat plots were planted with Roughrider in 1999 and Crimson in 2001. We were unaware of publications that have compared BYDV symptom expression or resistance in Roughrider versus Crimson wheat. We tested for differences by artificially infesting Roughrider and Crimson plants in the seedling stage with viruliferous *R. padi* and allowing plants to grow in the greenhouse. Early during the period of seed head emergence, symptoms of BYDV infection (i.e., stunting, erect leaves, and slight discoloration of flag-leaf tips) were pronounced and similar between varieties, and this result ruled out differential symptom expression or resistance as a factor in our field study.

Thus, differences in BYDV incidence were most likely because differences in the proportion of infective cereal aphids between fall 1999 and fall 2001. Similar to our results, Gillette et al. (1990) found three different combinations of cereal aphid infestation levels and BYDV incidence in France, with *R. padi* as the predominant aphid. They found high BYDV incidence associated with high *R. padi* infestation levels in three cropping seasons, low BYDV incidence but high *R. padi* levels in a fourth season, and low BYDV incidence and low *R. padi* infestation levels in the fifth year.

At Brookings, yield was negatively correlated with BYDV incidence but not with total cereal aphid or *R. padi* abundance. In contrast, yield at Highmore was negatively correlated with cereal aphid abundance but not with BYDV incidence. Early plantings at Brookings in 1999 and 2001 surpassed a mean >300

aphid-days per tiller, but the infestations were not associated with yield loss. This result contrasts with growth chamber-greenhouse studies that have shown cereal aphid infestations of 300 aphid-days cause yield loss in winter wheat (Kieckhefer and Gellner 1992, Riedell et al. 1999). However, a field cage study by Riedell et al. (2003) showed that 300 *R. padi*-days caused a modest reduction in kernel mass but had no effect on number of kernels or grain yield. The correlation between *S. graminum* aphid-days and yield loss at Highmore is consistent with results of Kindler et al. (2002), who showed a correlation between *S. graminum*-days and yield loss in wheat.

BYDV may cause highly significant yield loss in winter wheat (Fitzgerald and Stoner 1967, Hoffman and Kolb 1998, Riedell et al. 1999, Chapin et al. 2001), although Pike (1990) showed that loss from BYDV is generally less severe and occasionally nonsignificant with natural infections. Our results with BYDV incidence and wheat yield are largely consistent with results of other, recent planting date studies that have relied on natural infections. McGrath and Bale (1990) failed to show yield differences among three staggered plantings of winter wheat despite greater incidence of cereal aphids and BYDV with earlier planting. Chapin et al. (2001) found no differences in yield loss among three autumn plantings of winter wheat over a 3-yr period but showed that BYDV incidence correlated with yield loss over a 9-yr period. Kelley (2001) found that BYDV reduced grain yields of early planted wheat in 2 of 6 yr, and Ismail et al. (2003) found that aphid-days and BYDV were relatively minor factors in yield loss of winter wheat.

Our results have implications for management of winter wheat in South Dakota, because they suggest that planting after 20 September may significantly reduce the risk of damage from chewing insects, and reduce cereal aphid infestations and resulting BYDV incidence. Conversely, planting winter wheat before 20 September may require use of insecticides or resistant cultivars to suppress pest insects. Several studies have demonstrated yield preservation by using insecticides to suppress natural fall infestations of cereal aphids and resulting BYDV infection (Hammon et al. 1996, Chapin et al. 2001, Kennedy and Connery 2001). Late planting also seems advantageous with regard to other potential arthropod and viral disease problems (e.g., spring cereal aphid infestations and wheat stem maggot), because we found no evidence that late planting favored these pests.

The range of suitable planting dates for winter wheat may be much broader than the 3-wk period in which significant risk of aphid infestation and BYDV infection occur, but we are unaware of recently published studies that have compared yield of contemporary winter wheat cultivars over a range of planting dates in South Dakota. Our results showed reduced yield in late planting for only one of six site-years. Because late planting is an advisable practice to manage insects and viral disease, further study is needed to determine the feasibility of planting of winter wheat over a broader and particularly later range of dates in South Dakota.

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